CROSS REGION ANALYSIS, PATH CORRECTIONS AND THE TRANSPORTABILITY OF REGIONAL SEISMIC DISCRIMINANTS

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ABSTRACT

This study has investigated the problem of transporting regional discriminants, principally the regional *P/S* amplitude ratio and *Lg* spectral discriminants, between regions of differing tectonic type. The effects of differential regional phase attenuation and propagation blockages need to be taken into account and corrected before decision criteria for discriminants developed in one tectonic region can be transported to a different tectonic region. We have developed a set of frequency-dependent distance correction curves to correct the *Pn/Sn* and *Pn/Lg* amplitude ratio to a standard distance. Similar corrections have been developed for the *Lg* spectral ratio using a standard *Lg* attenuation model. Also, we have developed a method, called *cross-region seismic event characterization*, to characterize and identify new events which occur in aseismic regions or regions lacking known source types. Discrimination processing results of the Intelligent Seismic Event Identification System (ISEIS) for many different regions are stored in an Oracle database and can be called up on a regionalized basis. When a new event occurs, the method of cross-region seismic event characterization tries to find reference events from different regions, probably recorded at different stations than the new event, but at comparable distance for comparison which can be used as reference or training events to identify the new event. We construct crustal cross sections for the different propagation paths and determine if the new event has similar cross sections as the reference events. If the paths are not too different, the discriminants can be directly compared, after correcting for differences in distance. For paths that are very different, canonical correlation analysis of waveform features, such as the *Pn/Lg* amplitude ratio in different frequency bands, with propagation path parameters provides an empirical method for predicting the change in the feature, due to differences in propagation path effects (e.g., blockage and scattering). These correlations can be used to calibrate different tectonic regions and correct the discriminants being transported from one region to another. We have used this method to characterize a recent event of high interest, the January 5, 1995 Urals event, which was located in a known Russian mine. *Pn/Lg* ratios, measured at the Russian station Arti (ARU), were compared with earthquakes and nuclear explosions recorded at the Chinese station Urumchi (WMQ). Analysis of the propagation path cross section in China and Russia seemed similar, although seismic attenuation may be greater in China. This comparison revealed that the event had large shear waves, and therefore lower *Pn/Lg* ratio comparable to earthquakes but much lower than nuclear blasts. Therefore, the event has been identified as either a rockburst or mine collapse, and not an explosion.

OBJECTIVES

The objective of this project has been to investigate regional seismic waveform discriminants in a number of diverse tectonic regions to investigate the problem of discriminant transportability. Global seismic event identification for a CTBT requires discriminants which are insensitive to propagation path effects or can be corrected for propagation effects. In our research, we have tried to understand the effects of propagation path variations on regional waveform discriminants, to derive path corrections for discriminants, and to calibrate discriminants to different tectonic regions. Also, this study has investigated the performance of various regional discriminants to the different regions. This paper discusses the results of a just completed study of the transportability of regional seismic discriminants and presents plans for research in a new project on discriminant transportability which is pending.

RESEARCH ACCOMPLISHED

Cross-Region Seismic Event Characterization

Past studies of regional seismic discriminants have revealed that certain simple seismic measurements can be used as discriminants between classes of known earthquakes and explosions, including conventional economic explosions (mine blasts) and nuclear explosion tests. These include frequency dependent ratios of amplitudes of different phases, in particular, regional *P/S* (e.g., Bennett et al, 1989; Baumgardt and Young, 1990; Kim et al, 1993), spectral ratios on individual regional seismic phases (Murphy and Bennett, 1982; Bennett and Murphy, 1986; Taylor et al, 1988; Taylor et al, 1989; Walter et al, 1994), and the detection of ripplefire by the identification of spectral scalloping (Baumgardt and Ziegler, 1988; Hedlin et al, 1989; Hedlin et al, 1990; Kim et al, 1994). Most discrimination studies have sought events of different source types in the same, geographically confined region, in order to quantify the source discriminants and eliminate any differences due to propagation path.

However, a major problem with monitoring afuture CTBT will be characterizing and identifying seismic events that can occur anywhere in the world. Thus, we may not have the luxury of identifying new events with training or reference events in the same region with common propagation paths. To address this problem, we have analyzed these discriminants, implemented in the Intelligent Seismic Event Identification System (ISEIS) (Baumgardt et al, 1991), and applied to many mine blasts, rock bursts, and nuclear explosions and earthquakes in Russia, Scandinavia, Germany, Poland, and China. ISEIS discrimination-analysis results are stored in an Oracle database, and these results can be recalled on a regional basis. Thus, we can compare discrimination results in different regions with each other, which provides useful insights about regional performance of discriminants. Our approach has been to compare seismic events recorded at different stations in different region but at comparable distances. We then attempt to characterize and quantify differences in discriminant performance with differences in the propagation path effects due to differences in the tectonic regions.

Figure 1 shows a flow diagram for our concept for cross-region seismic discriminant characterization and calibration. Given a new event to characterize, we check the database for reference events located in the same region and recorded at the same station. Quite often, however, few events may be available. Thus, to characterize the event, it will be necessary to access events from another region by a different station but at the same distance.

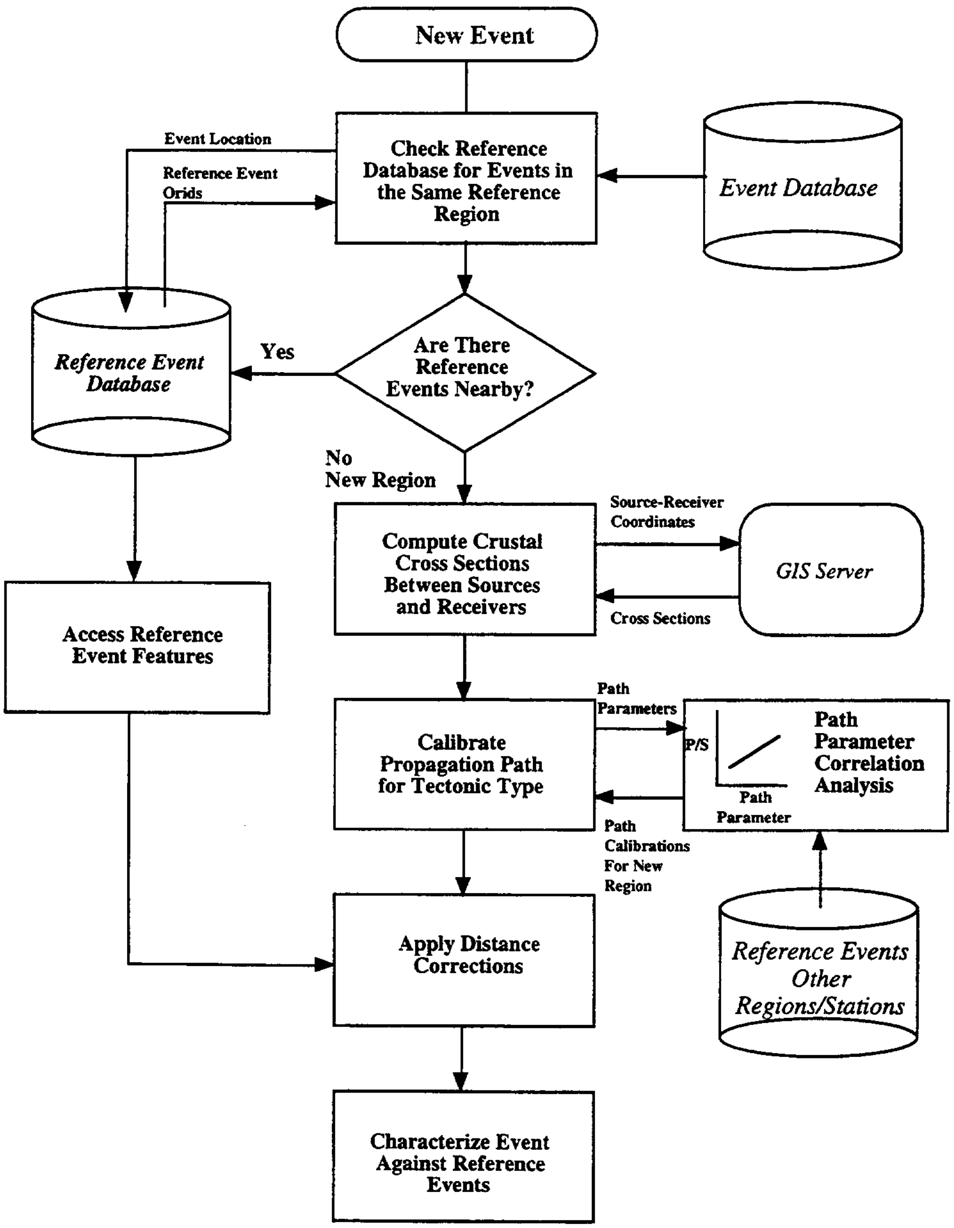


Figure 1: Method for accessing and utilizing reference events for event characterization. If the event occurs in a region where previously identified events have been studied, these events can be used to characterize the event. If not, events from other regions, perhaps recorded at other stations, must be used. Path parameter and seismic waveform feature correlations are then used to calibrate the *P/S* ratio discriminant from one tectonic region to another.

However, discriminants may be biased from one region to another because of differences in the seismic propagation in the different regions. We attempt to quantify these differences by comparing crustal cross sections for the propagation paths in the different regions utilizing crustal structure information now available from on-line GIS servers (e.g., Barazangi et al, 1995). Propagation paths can be parameterized in terms of elevations, crustal thicknesses, depth to sediments, and variations in these quantities (Zhang et al, 1994; Baumgardt and Der, 1994). If the different propagation paths have similar parameters, seismic discrminants in the same regions may be directly compared, provided they have been corrected for distance. If they differ, canonical correlation analysis (e.g., Zhang et al, 1994; Baumgardt and Der, 1994) can be used to calibrate discriminants for different regions prior to distance correction.

Cross-region characterization was used to analyze and identify a recent event which occurred on January 5, 1995 near a mine in Russia (Baumgardt, 1995). Figure 2 shows the location of the event and the stations which recorded it .The Russian media announced that the event was "tectonic", i.e., associated with an earthquake which apparently induced considerable damage in the mine. Also shown are a number of historical PNEs which occurred in the same region. Aside from these PNEs, we know of no other seismicity in the region. Also, the PNEs occurred before the nearest alpha station ARU was installed, so we have no reference events in the same region recorded at ARU to compare with the January 5 event.

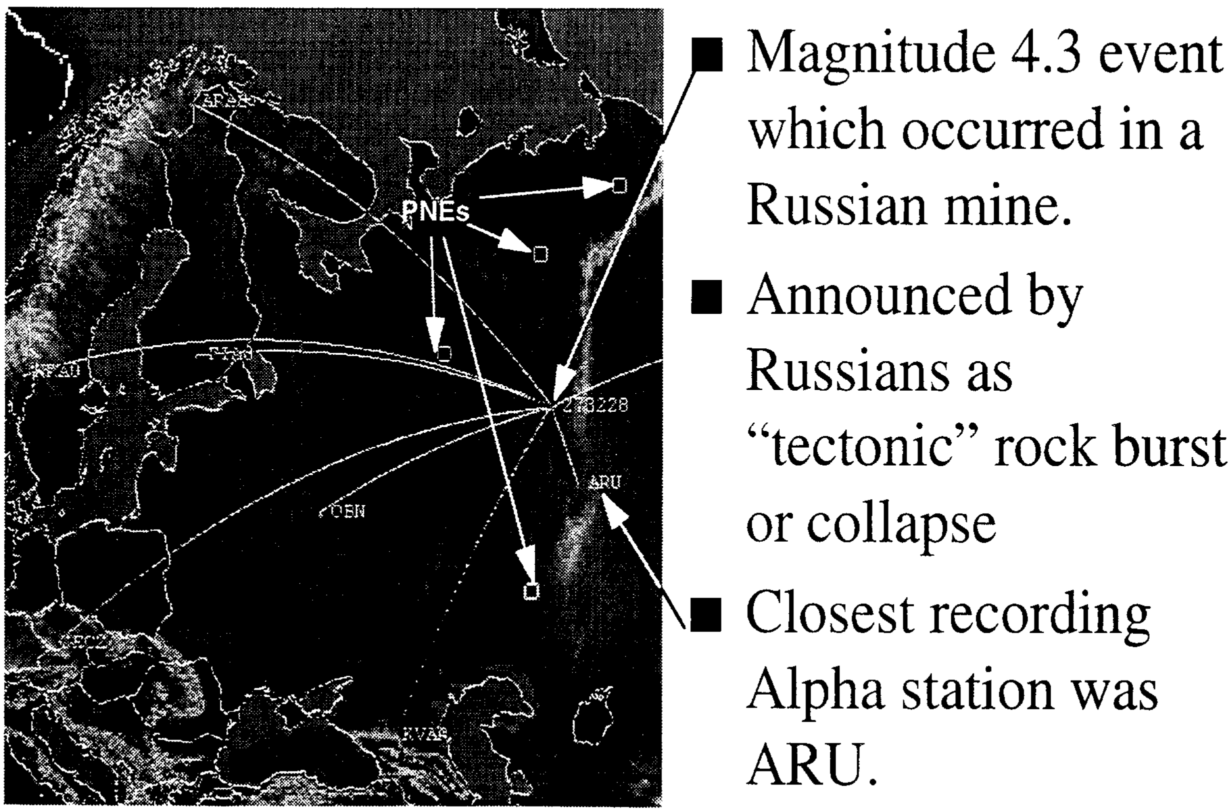
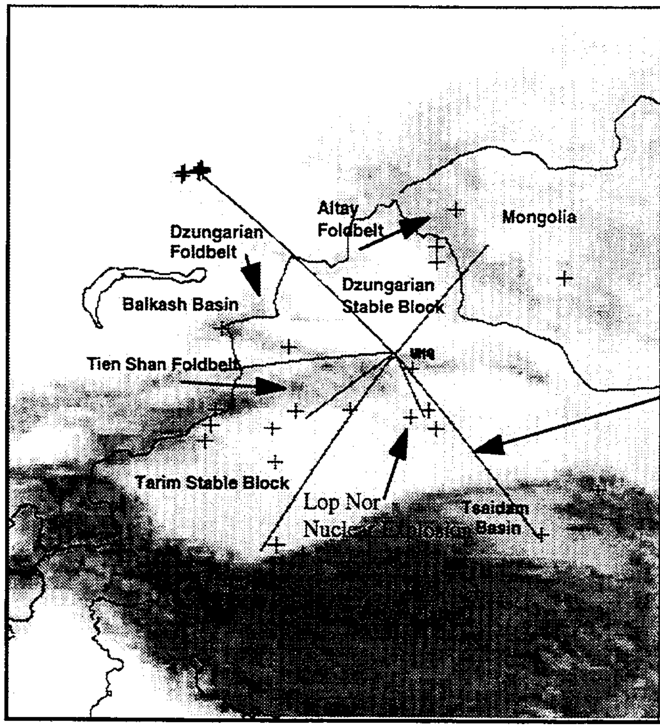


Figure 2: Map showing location of the January 5, 1995 S. Urals events and the alpha stations which recorded the event. Also shown are location of nearby PNEs.

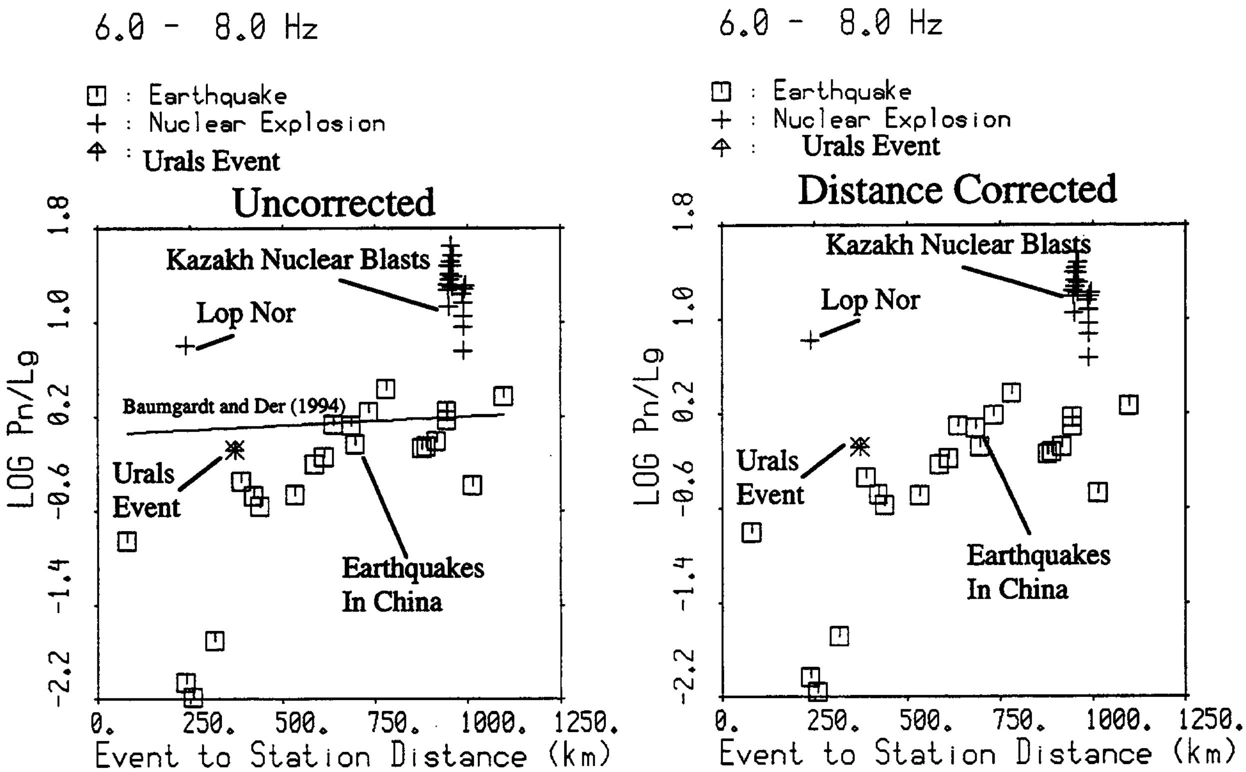
This event was of high interest because it was located in a known Russian mine and also in a region where PNEs have been detonated in the past. Because of the lack of reference events in the region recorded at ARU (no PNEs have been recorded at ARU), Baumgardt (1995) compared the event with earthquakes and explosions in China and Russia recorded at the station Urumchi (WMQ) in China, originally studied by Baumgardt and Der (1994) and shown on the map in Figure 3. The justification for this comparison, even though the Ural and Chinese events occurred in different regions and were recorded at different stations, is that the distances and propagation paths in the ARU and WMQ regions are similar. Also, because we are comparing ratios between phases in the same frequency band, the difference in the ARU and WMQ instrument response is not a factor. However, we may expect greater attenuation in the crust of China than in the more shield-like Russian Platform, which may result in large *Pn/Lg* ratios in China than in Russia at the same distances.



- Lack of reference events in Eurasia for Urals event requires comparison with Chinese events.
- Geology of propagation paths from earthquakes to Chinese station WMQ comparable to Urals path to ARU.
- Greater attenuation in China may produce larger *Pn/Lg* ratios (greater *Lg* attenuation) than in Russia.

Figure 3: Chinese events recorded at the stations WMQ which are compared to the S. Urals event recorded at ARU.

Figure 4 shows a distance plot of the measured *Pn/Lg* ratios in the 6 to 8 Hz band from the Ural event at ARU and the WMQ recordings of Chinese earthquakes and nuclear explosions recorded at the WMQ station. In Figure 4 (a), the distance-dependence of the Baumgardt and Der (1994) correction is superimposed. Over this distance range, the slope of the correction curve is amall. Thus, as shown in Figure 4 (b), correcting for distance with this function has little effect. After distance corrections, the Urals event appears to have *Pn/Lg* ratios, measured at ARU, which are comparable to earthquakes in China and much lower than those observed for nuclear blasts. This comparison strongly suggests that the Urals event was a tectonic event, such as a rockburst or mine collapse, since we would expect such events to have larger shear waves and lower *Pn/Lg* ratios.



(a) (b)

Figure 4: *Pn/Lg* ratios plotted versus distance for the WMQ recordings of Chinese earthquakes and Lop Nor and Kazakh nuclear blasts recorded at WMQ compared with the January 5, 1995 Urals event recorded at ARU. Distance correction of Baumgardt and Der (1994) is shown on the left and applied on the right.

Path Corrections for Regional *P/S* Ratio and *Lg* Spectral

During this project, a set of distance corrections were developed for the *P/S* ratio discriminant (Baumgardt and Der, 1994) and the *Lg* spectral ratio (Baumgardt, 1995). The *P/S* ratio corrections were developed empirically for several frequency bands from data in Scandinavia and Europe, and implemented in ISEIS for corrections of the *Pn/Sn* and *Pn/Lg* ratio discriminants. Figure 4 shows an example of the application of this correction for the 6-8 Hz band. For correction of the *Lg* spectral ratio, the affect of attenuation must be taken into account. We model the amplitude of a regional phase with the standard anelastic attenuation relation

$$A^{TH}(f,D) = A_o(f)\exp\left[\frac{-\pi f D}{QU}\right],$$

where A^{TH} is the theoretical spectral amplitude at frequency f and distance D, A_o is the initial source excitation, D is the distance in km, Q is the attenuation quality factor, U is the group velocity of the regional phase and f is the frequency in Hz. We assume the commonly used power-law frequency dependence for attenuation

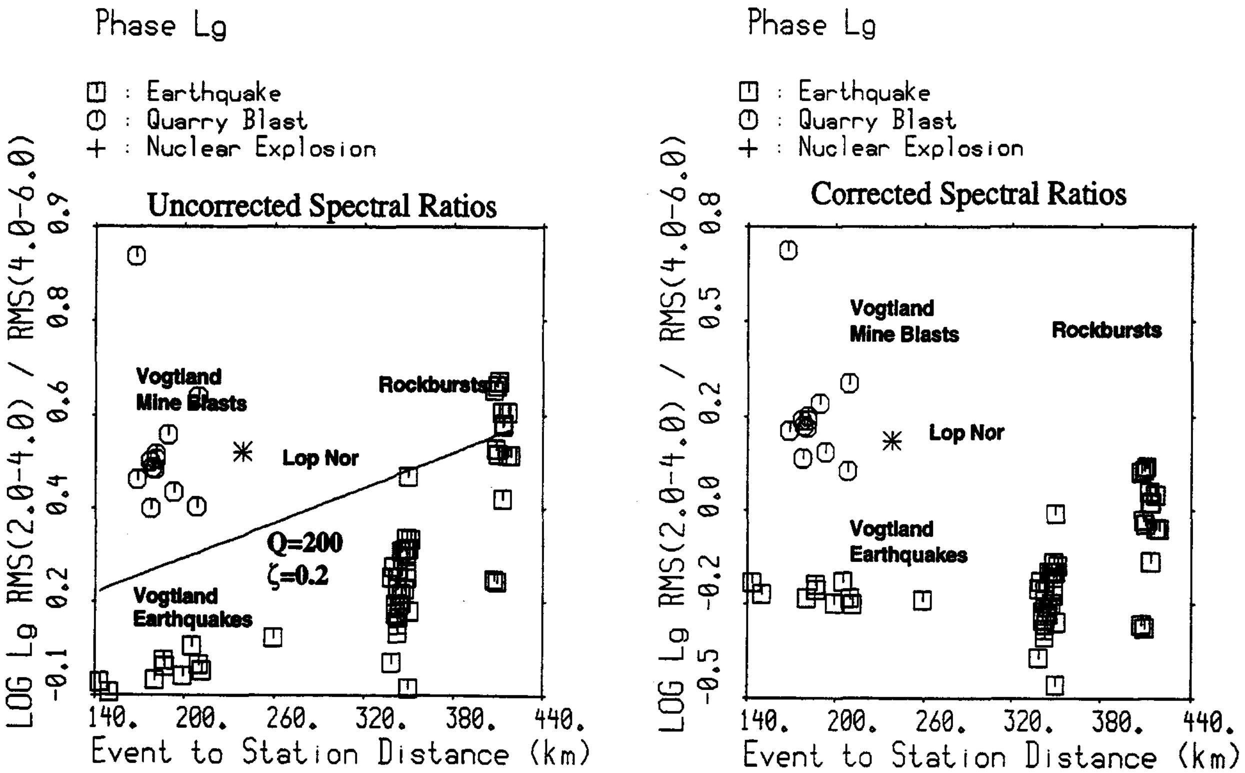
$$Q = Q_o\left(\frac{f}{f_o}\right)^{\zeta}$$

where Q_o is quality factor at the reference frequency f_o and ζ specifies the frequency dependence. Generally, f_o is 1 Hz and ζ ranges from 0.0 to 1.0. Given observed values of the rms spectral ratio between the low frequency band (Δf_1) and the high frequency band (Δf_2), $R(\Delta f_1,\Delta f_2,D)$, at distances D, we wish to correct the ratios to the same reference distance, D_{ref}. Assuming values of Q_o, ζ, and U, we have for the distance corrected spectral ratio

$$R(\Delta f_1,\Delta f_2,D_{ref}) = R(\Delta f_1,\Delta f_2,D)\frac{R^{TH}(\Delta f_1,\Delta f_2,D_{ref})}{R^{TH}(\Delta f_1,\Delta f_2,D)}.$$

Group velocities, U, of 8.1, 6.5, 4.7, and 4.0 km/sec were assumed for major regional phases, *Pn*, *Pg*, *Sn*, and *Lg*, respectively. Values of Q_o and ζ are dependent on the path and must be determined by direct inversion of *Lg* spectra or coda, or by trial and error by fitting trends by eye to spectral-ratio-versus-distance plots. In this study, we use the latter approach.

Figure 5 shows measurements of *Lg* spectral ratios for Vogtland mineblasts and earthquake in Germany and Polish rockbursts, originally studied by Baumgardt (1993).



(a) (b)

Figure 5: (a) GERESS spectral ratios for Vogtland and Polish rockbursts with distance correction curve for Q=200 and ζ=0.2. (b) Result of correcting the spectral ratios for anelastic attenuation. Note now that the rockburst points are lowered and now discriminate from the mine blasts after the distance correction is applied.

This discriminant easily separated the Vogtland mineblasts and earthquakes. However, as shown in Figure 5 (a), the more distant rockburst points have larger values and greater scatter than the mineblasts. The rockbursts, being similar to earthquakes, might be expected to discriminate from mine blasts in the same way as earthquakes, and the increasing spectral ratios with distance may be due to anelastic attenuation. Based on trial and error plotting of different attenuation correction curves, we conclude that the curve for $Qo = 200$ and $\zeta = 0.2$ seems to pass through the extreme values of the earthquakes and rockbursts, as shown in Figure 5 (a). Assuming this correction curve, we get the distance-corrected spectral ratios shown plotted in Figure 5 (b). After correction, the rockburst points at larger distance are shifted downward and more closely resemble the values of Vogtland earthquakes. Thus, in this instance at least, the increased scatter of the rockbursts may have been due to their increased distance. We conclude that, after distance corrections, the rockbursts in Poland are similar to earthquakes and that both *Pn/Lg* ratios and *Lg* spectral ratios can classify events in this region.

CONCLUSIONS AND RECOMMENDATIONS

We have found cross-region discriminant analysis to be a useful method for characterizing seismic events which have occurred in regions with limited historical record of explosions and earthquakes. When corrections for distance are made, events in different regions can be used to identify events in other regions, even when recorded at the same stations. We have determined path corrections for *P/S* amplitude ratios and *Lg* spectral which reduce systematic bias due to distance effects and improve the performance in separating explosions and earthquakes.

There still remains the problem of calibration of regional discriminants when transporting them between extremes of tectonic type. For example, waveform discriminants developed in the Scandinavian shield cannot be directly used to discriminate events in the tectonically active regions China, even after distance correction, without proper calibration for the differences in propagation in the two tectonic regions. The canonical correlation analysis of Zhang et al (1994) and Baumgardt and Der (1994) may be a promising first step towards developing these calibrations. Modeling studies may also be a useful means for determining sensitivities of regional discriminants to crustal parameters which can be used for calibration. In future reearch, we plan to continue investigating this approach, extending it to propagation paths and regions in the Middle East as data becomes available.

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